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Survey of Flue Gas Desulfurization Systems: La Cygne Station, Kansas City Power and Light Co

PEDCo-Environmental, Inc, Cincinnati, Ohio

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, N C

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16. ABSTRACT The report gives results of a second survey of the flue gas desulfurization (FGD) system on Unit 1 of Kansas City Power and Light Co.'s La Cygne Station. The FGD system, first started up in February 1973 and commercially available in June 1973, utilizes a limestone slurry in eight scrubbing modules to control fly ash and SO2 from the combustion of high sulfur subbituminous coal. Each module includes a venturi scrubber, sump, and two-stage sieve tray absorber. All the flue gas is treated: it cannot bypass the scrubbing modules. Facilities for limestone grinding and storage and final disposal of the flue gas cleaning wastes are on the plant grounds. Clear water is recycled from the pond to the FGD system for additional use. SO2 and particulate removal efficiency measurements indicate that the design values of 80 and 98.75%, respectively, have been met or exceeded.

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Flue Gases	Coal	Stationary Sources	21B 21D
Desulfurization	Combustion	Wet Limestone	07A,07D
Fly Ash	Cost Engineering	Particulate	14A
Limestone	Sulfur Dioxide		07B
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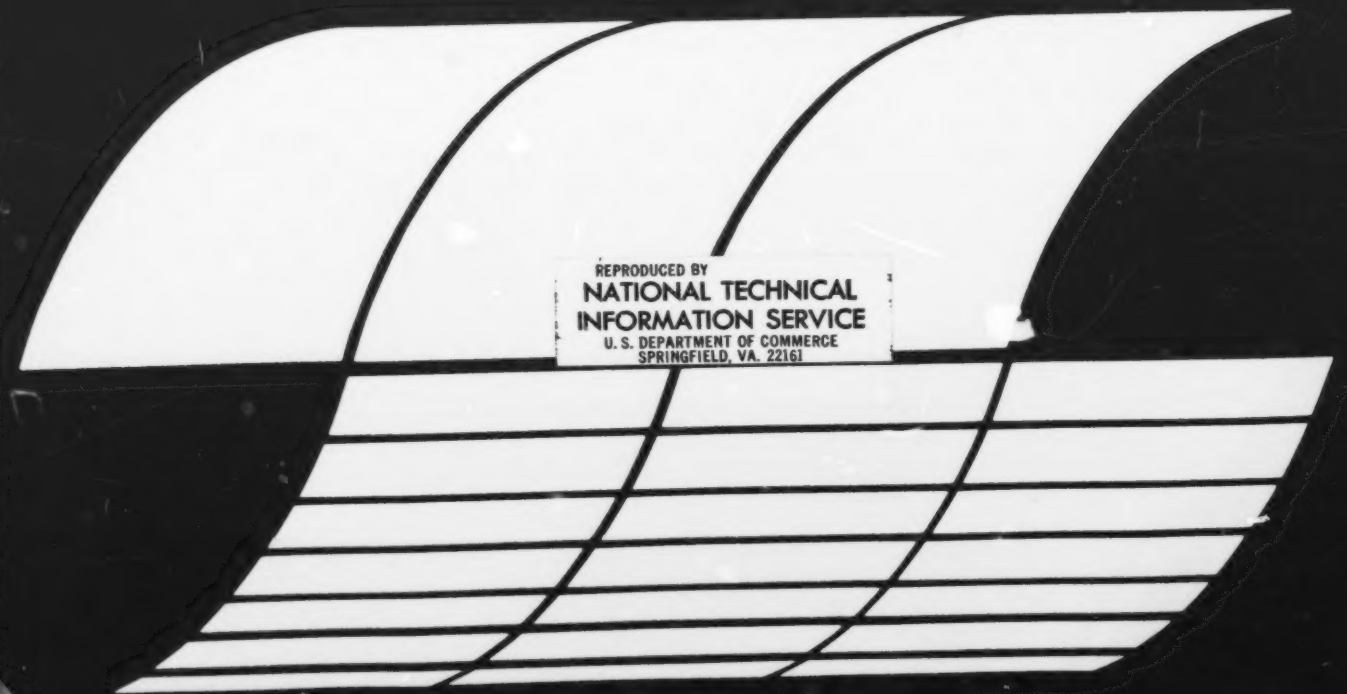

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SUMMARY

The wet limestone FGD system at the La Cygne Power Station of the Kansas City Power and Light Company simultaneously removes particulates and sulfur dioxide from flue gases. This scrubbing system, which consists of eight modules, was designed and fabricated by the Babcock & Wilcox Company and installed as an integral part of the electric power generating facility. All flue gases are treated, and the ductwork is arranged so that they cannot bypass the FGD modules. Facilities for limestone grinding and storage and final disposal of flue gas cleaning wastes are located on the plant grounds.

Construction started in April 1969 and reached the halfway point in October 1971, at which time the construction force exceeded 900 men. Unit 1 was nearing completion when the boiler was first fired on December 26, 1972, and was considered complete when the generating unit was declared commercial on June 1, 1973. This date was only 1 month behind schedule. The peak generating load (832 MW) was attained on June 2, 1973.

Initial operation of the FGD system began in February 1973, and full commercial operation, on June 1, 1973. Several major problems accompanied start-up and subsequent operation of the FGD modules. These included massive scale formation, widespread corrosion, induced-draft-fan problems related to vibration and bearing overheating, limited capability of limestone preparation and handling systems, valve and piping failures, nozzle plugging, pump liner failures, and control malfunctions.

Many modifications had to be made in the design and operation of the system to overcome the operational problems without applying a 100-man work crew or imposing sizable load restric-

tions. These modifications resulted in improved mechanical reliability and cost-effective operation.

The total FGD system availability index* has increased steadily each year since commercial start-up. Values achieved in 1974, 1975, 1976, and 1977 were 76, 84, 92, and 93 percent, respectively. These values indicate an annual average increase of approximately 4 percent.

The utility conducted a series of stack sampling tests in March and May of 1975 to check the efficiency of the system. Testing was at full load and maximum continuous load. Results showed particulate and SO_2 removal efficiencies of 98.2 and 80.14 percent, respectively, an indication that design values were being attained.

The system is designed for closed-water operation. Spent limestone slurry and fly ash are removed to a 0.65-km^2 (160-acre) unlined settling pond via rubber-lined piping. Clear makeup water is returned to the process. The loop is closed by recycling ball mill and module makeup water into the system.

Initial installed capital cost of the La Cygne wet scrubbing system was approximately $34 million, which is equivalent to $41/kW for a net generating capacity of 820 MW. Subsequent equipment modifications have increased the cost to about $47 million or $59/kW. The reported operating cost for 1977 was 1.69 mills kWh ($1.79 million), which includes operating materials, operating labor, maintenance materials, maintenance labor, and limestone.

In April 1977 the utility completed installation of an additional FGD module, which went into commercial service on July 5, 1977. The capital cost of this eight module was approximately $5.2 million. Its installation enabled the utility to increase the maximum net continuous generating capacity of the unit from 700 to 800 MW and still comply with emission regulations.

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* Availability index: the number of hours the FGD system is available for operation (whether operated or not), divided by the number of hours in the period, expressed as a percentage.

Table 1 summarizes pertinent data on the facility and the FGD system.

Table 1. DATA SUMMARY: LA CYGNE FACILITY AND FGD SYSTEM

Unit rating, net MW	820
Fuel	Coal
Fuel characteristics	
Type	Subbituminous
Gross heating value, MJ/kg (Btu/lb)	21 to 23 (9000 to 9700)
Ash content, %	25
Sulfur content, %	5
FGD system supplier	Babcock & Wilcox
Process	Wet limestone scrubbing
New or retrofit	New
Initial start-up date Commercial start-up date	February 1973 June 1973
Number of FGD modules	8
Removal efficiency, %	
Particulate (measured)	98.20
Sulfur dioxide (measured)	80.14
Sludge disposal	Unstabilized sludge is disposed of in an on-site unlined pond
Unit cost	
Capital (1977)	$46.8 million or $59/kW net
Operating[a] (1977)	$3.038 million or 1.693 mills/kWh

[a] The reported operating costs are for the first 9 months of 1977.

SECTION 1

INTRODUCTION

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has initiated a study to evaluate the performance characteristics and reliability of flue gas desulfurization (FGD) systems operating on coal-fired boilers in the United States.

This report, one of a series dealing with FGD systems, describes a limestone scrubbing process developed by Babcock & Wilcox (B&W) and installed at the La Cygne Power Station of Kansas City Power and Light Company (KCP&L).

This report updates an earlier one that was based on information obtained during an inspection of the La Cygne Power Station on June 5, 1974, and on data provided by utility and system supplier personnel during that visit. The installation was visited again on June 23, 1976, to gather additional information for this report. The utility has also provided additional data since the second visit.

Section 2 provides information and data on facility design and operation. Section 3 describes the FGD system, the process chemistry, and the control strategy. Section 4 presents an analysis of FGD system performance. The appendices present details of plant and system operation.

SECTION 2

FACILITY DESCRIPTION

The La Cygne power station is a new coal-fired facility, jointly owned by the Kansas Gas and Electric Company and KCP&L. It is located in Linn County, Kansas, 88 km (55 miles) due south of Kansas City. The site is surrounded by relatively flat farmland and pasture. There are no other major industrial facilities in the immediate area. The nearest population center is the town of La Cygne (approximately 1000 people), which is located approximately 9.6 km (6 miles) west of the station.

Unit 1 at La Cygne is a wet-bottom, cyclone-fired, boiler manufactured by B&W. This supercritical, once-through balanced-draft unit generates 2800 Mg (6,200,000 lb) of steam per hour, with 543°C, 26.3 MPa (1010°F, 3825 psig) at the superheat outlet and 543°C (1010°F), at the reheater outlet. The turbine generator, manufactured and supplied by the Westinghouse Company, has a design-rated gross output of 874 MW, with 5 percent overpressure and 24 MPa (3500 psi) throttle pressure. The station also contains three auxiliary oil-fired boilers, which are used for plant start-ups or to power a 20-MW house turbine generator. Since 30 MW of the total gross megawatt rating of the turbine generator is used to power the plant's auxiliary equipment and 24 MW is required to operate the emission control system, the net electrical power output is 820 MW.

Particulate and SO_2 emissions are controlled by a system consisting of eight identical modules, each with a two-stage venturi scrubber and tray tower absorber. These modules were designed, manufactured, and installed by B&W as an integral part of the power generating facilities. Ductwork is arranged so that flue gases cannot bypass the scrubbing modules.

The boiler burns low-grade, subbituminous coal, which is delivered to the plant in off-the-road 108-Mg (120-ton) trucks from nearby surface mines operated by the Pittsburgh & Midway Coal Mining Company. Deposits at these mines are estimated at 70 million tons. This supply is considered adequate for the life span of La Cygne Unit 1. Table 2 presents a typical analysis of this coal.

Table 2. TYPICAL ANALYSIS OF LA CYGNE NO. 1 COAL

(percent except as noted)

Description	Value
Heating value (as-fired), MJ/kg (Btu/lb)	21.95 (9421)
Volatile matter	28.63
Fixed carbon	37.94
Sulfur	5.39
Ash	24.36
Chloride	0.027
Moisture	8.60
Grindability	59.59

The utility has installed a second electric power-generating unit (Unit 2), rated at 630 MW. Power is supplied to the generator from a coal-fired boiler that fires low-sulfur Wyoming coal (0.32 % sulfur). Unit 2 was placed in commercial service on May 15, 1977. The emission control system for this second unit consists of a full-capacity electrostatic precipitator (ESP), supplied by Lodge-Cottrell, for primary particulate control. Burning low-sulfur coal enables plant operators to comply with SO_2 emission regulations without controls.

For Unit 1, the maximum particulate emission allowed under Kansas State Department of Health and Environment Regulation No. 28-19-31-A is 60 ng/J (0.13 lb/10^6 Btu) of heat input to the boiler. A test measuring particulate emission from the FGD

system showed actual emissions to be equivalent to 77.5 ng/J (0.18 lb/10^6 Btu).

The maximum sulfur emission allowed under Regulation No. 28-19-31-C is 645 ng/J (1.5 lb/10^6 Btu) of heat input to the boiler. The present SO_2 emission rate from the La Cygne station, based on 80 percent removal efficiency in the FGD system, is equivalent to about 860 ng/J (2 lb/10^6 Btu). This figure is based on 95 percent conversion of the sulfur to sulfur dioxide. Thus, the actual SO_2 emissions are well below the emission limitation level of 1290 ng/J (3 lb/10^6 Btu).

Table 3 presents data on plant design, operation, and atmospheric emissions for Units 1 and 2. Figure 1 is a process flow diagram of the La Cygne wet limestone FGD system, including the additional module now in service.

Table 3. DESIGN, OPERATION AND EMISSION DATA, LA CYGNE UNITS 1 AND 2

Description	Unit 1	Unit 2
Maximum generating capacity, net MW	820	630
Boiler capacity factor, percent (1977)	44	80
Served by stack no.	1	2
Boiler manufacturer	B&W	B&W
Year placed in service	1973	1977
Maximum coal consumption:		
Mg/hr (Short tons/hr)	366 (404)	
Maximum heat input:		
GJ/hr (10^6 Btu/hr)	8100 (7676)	
Stack height above grade:		
Meters (ft)	213 (700)	213 (700)
Design maximum flue gas rate:		
m^3/sec acfm	1300 2,760,000	1250 2,643,000
Design flue gas temperature, °C (°F)	140 (285)	302 (150)
Emission controls:		
Particulate	Venturi scrubber	Electrostatic precipitator (Lodge-Cottrell/ Dresser Industries)
SO_2	Venturi scrubber and counter-current absorber tower	None; low-sulfur coal
Particulate emission rate:		
Allowable, ng/J (lb/10^6 Btu)	56 (0.13)	43 (0.10)
Actual, ng/J (lb/10^6 Btu)	775 (0.18)	
SO_2 emission rate:		
Allowable, ng/J (lb/10^6 Btu)	645 (1.5)	516 (1.2)
Actual, ng/J (lb/10^6 Btu)	860 (2.0)	

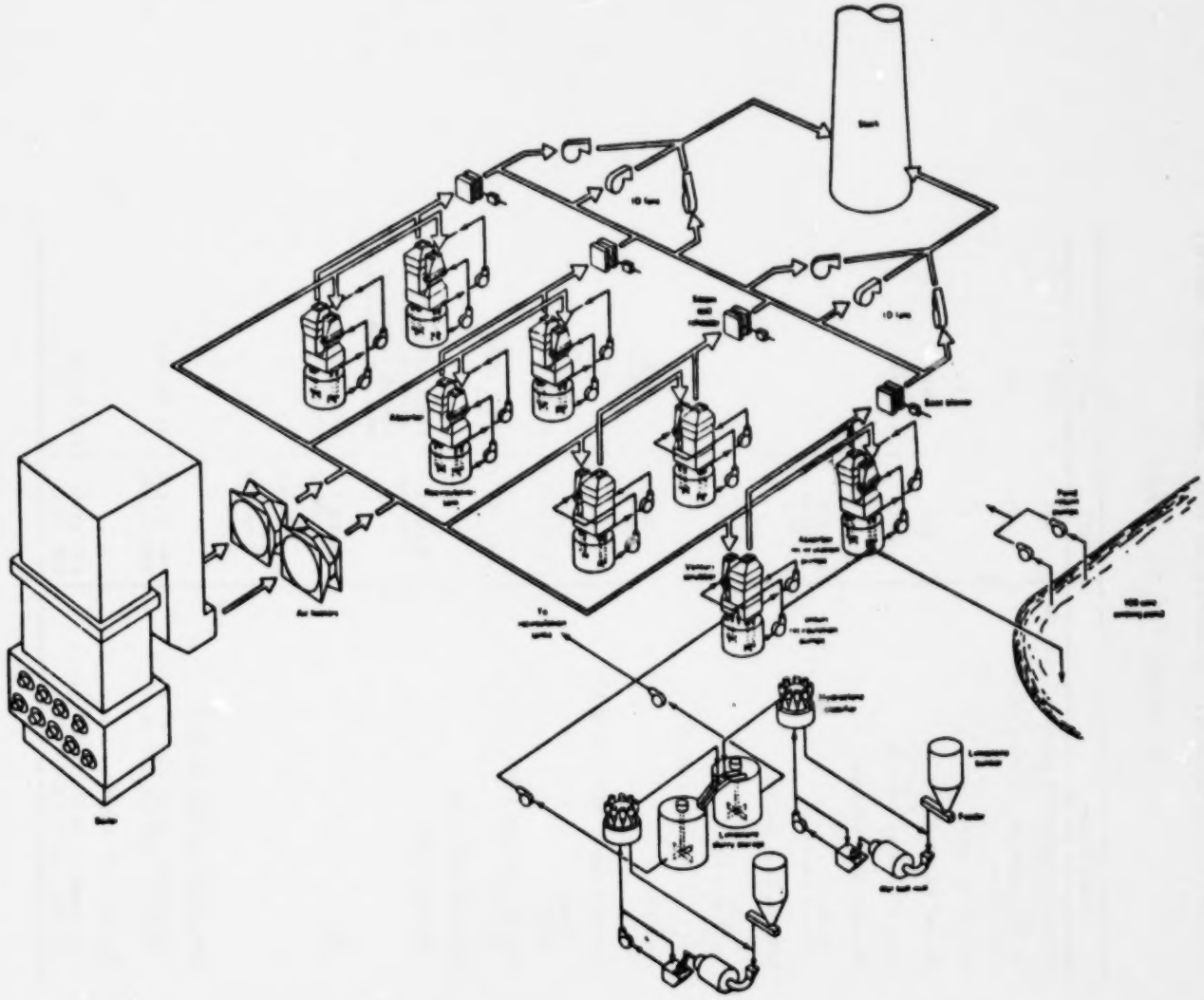

Figure 1. Process flow diagram for the La Cygne No. 1 scrubbing system.

SECTION 3

FLUE GAS DESULFURIZATION SYSTEM

BACKGROUND INFORMATION

The wet limestone FGD system at the La Cygne Power Station was designed, fabricated, and installed by B&W. The research, development, bench-scale work, and pilot-plant testing that ultimately led to the development of this process took place at B&W's Research and Development Center in Alliance, Ohio.

B&W originally became involved in FGD technology late in the 1960's when they initiated a research and development program on both regenerable and nonregenerable scrubbing processes. Experimental work in nonregenerable processes eventually led to the investigation of a number of chemical-based processes for removal of SO_2 as a waste product. The investigation included bases such as sodium carbonate, sodium hydroxide, ammonia, lime, and limestone. Economics were also considered. Factors such as raw material costs and necessary waste handling equipment eventually led to emphasis being placed on a process using limestone slurry and a design configuration that would allow SO_2 removal from flue gas streams at a minimum efficiency of 80 percent.

Follow-up research on limestone FGD processes consisted of mathematical and computer modeling, factorial analyses of process variables, chemical analyses evaluating the suitability of various types of limestone, further and more detailed economic analyses, and, finally, the construction of a pilot plant at B&W's Research Center in Alliance.

A schematic equipment and flow diagram of the pilot facility is presented in Figure 2. The pilot plant contained the follow-

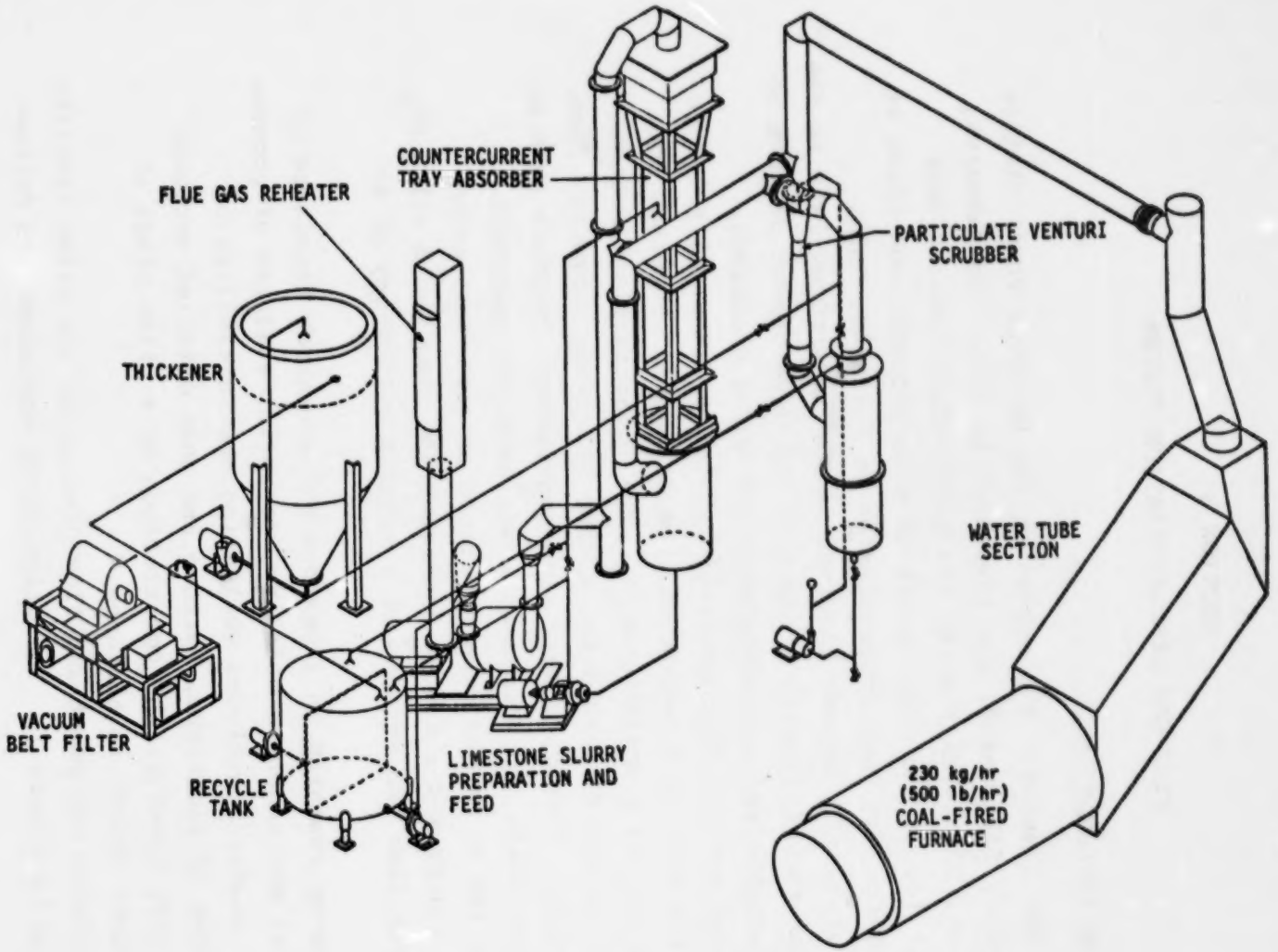

Figure 2. B&W wet-limestone-scrubbing pilot plant facility.

ing components: a 230 kg/hr (500 lb/hr) pulverized-coal furnace, a steam generating bank, a venturi scrubber and countercurrent tray absorber module, a steam coil gas reheater, and an induced-draft fan. The pilot facility also included a limestone preparation and circulation system, a thickener, and a vacuum belt filter.

The facility design allows maximum water recovery which makes it possible to determine the effects of dissolved solids buildup and scale formation potential of various types of limestone and fuel.

Following completion of the pilot program, a full-scale facility was installed for demonstration on the new coal-fired boiler at the La Cygne power station.

PROCESS DESCRIPTION

The La Cygne wet limestone FGD system consists of eight scrubber-absorber modules designed to treat the total boiler flue gas load capacity of 1300 m^3/sec (2,760,000 acfm). This is equal to 185 m^3/sec (394,300 acfm) per module at 140°C (285°F). Ductwork design is such that flue gas cannot bypass the scrubbing system, but the individual damper systems allow each module to be isolated for maintenance and repairs. Figure 3 presents a cutaway view of one of the scrubber modules.

Limestone is obtained from nearby quarries owned and operated by the Bates City Rock Co. and delivered to the plant site in off-the-road 45-Mg (50-ton) trucks. The delivered limestone consistently averages 1.9 cm. x 0 cm. (3/4 in. x 0 in.). A 54 Gg (60,000-ton) supply is maintained near the plant coal storage area. It is transported continuously by a separate conveyor system. Two wet ball mills, each capable of processing 100 Mg/hr (110 ton/hr) of limestone, grind the rock to a fineness of 95 percent minus 200 mesh at 66 percent solids before it is mixed into a slurry. The limestone has the following chemical characteristics: a minimum of 85 percent calcium carbonate, a maximum of 2.5 percent magnesium carbonate, 8 percent moisture, and 7

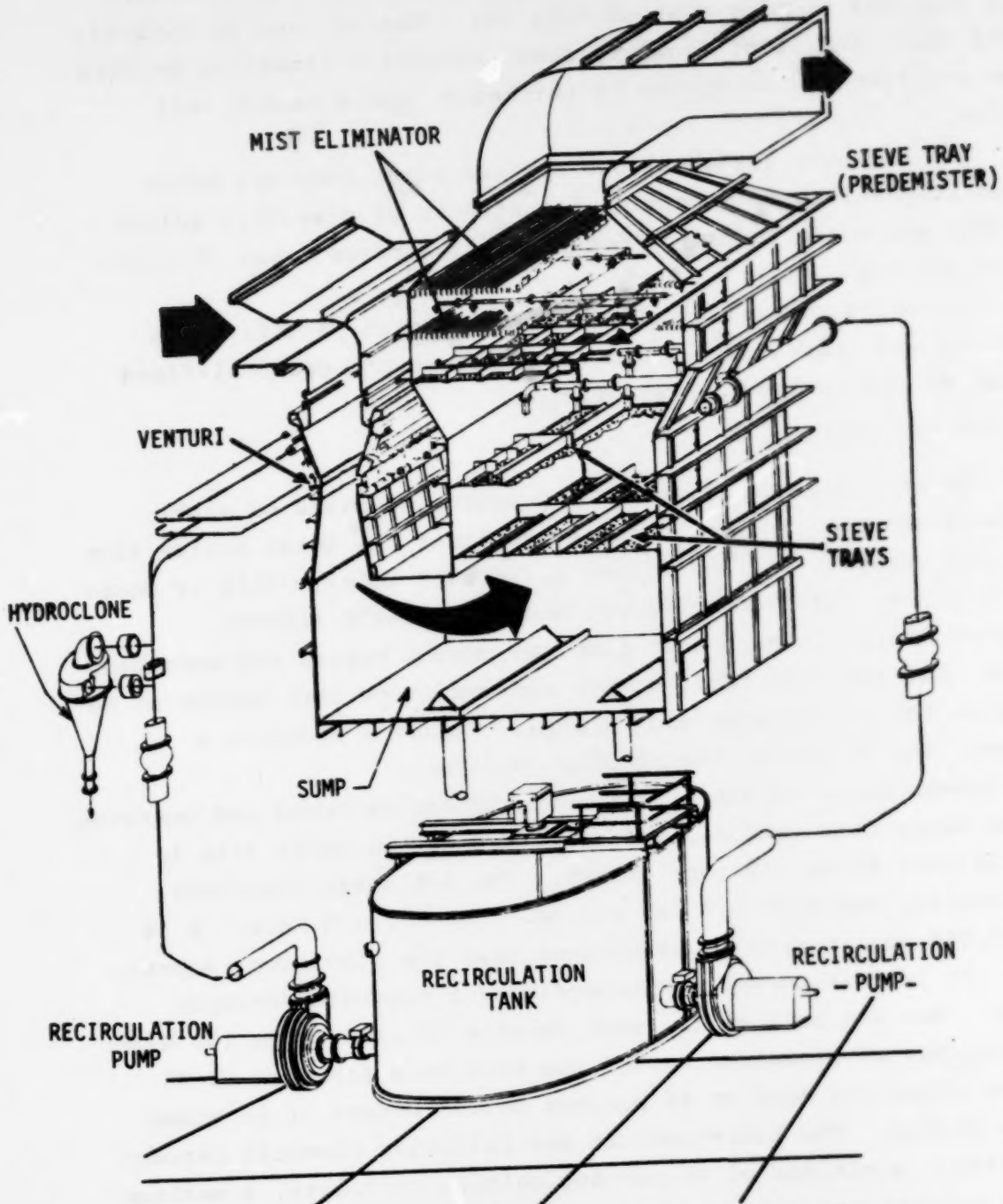

Figure 3. Cutaway view of a La Cygne FGD module and ancillary components.

percent gangue. The two ball mills are housed in a separate building, which also contains two limestone preparation tanks and two slurry tanks. The slurry, which is 20 percent solids by weight, is pumped to each module at a rate of 12.2 l/sec to 36 l/sec (200 to 600 gpm). Total annual limestone consumption is estimated to be 453 to 635 Gg (500,000 to 700,000 tons).

The hot boiler flue gas first enters the system through the venturi scrubber of each module, where it is contacted with jets of limestone slurry in a crosscurrent fashion. The slurry is injected into the flue gas by 48 spinner-vane spray nozzles. At this stage of the process, up to 99 percent of the particulates in the flue gas is agglomerated and collected in the sump below. Additional limestone slurry is injected through 32 wall wash nozzles around the periphery of the venturi. This step wets the convergent sides of the venturi, thereby preventing fly ash deposition and providing an additional interface. The venturi recirculation pump provides a continuous cycle of the slurry at a rate of 305 to 366 l/sec (5000 to 6000 gpm).

The gas flow continues through the sump, turns 90 degrees in an upward direction, and proceeds through a series of sieve trays. As the gas exits the venturi and flows through the sump into the absorber, its superficial velocity decreases from 39.6 m/sec (130 ft/sec) at the throat to 4.6 m/sec (15 ft/sec) and then to 2.6 m/sec (8.4 ft/sec) at the mist eliminator. The gas passes through two layers of stainless steel absorber sieve trays, which have 3.5-cm (1-3/8-in.) diameter holes and 38-cm (15-in.) skirts that form many open frothing boxes. Slurry is pumped to the absorber through 16 spinner-vane spray nozzles, where it showers through the trays counter to the flue gas flow. The SO_2 is removed from the flue gas and converted to calcium salts.

The cleaned gas passes through a predemister (actually a third stainless steel sieve tray), then upward through a 25-cm-

deep (10-in.-deep) chevron mist eliminator* constructed of fiberglass-reinforced plastic. Entrained moisture droplets are removed from the gas stream and fall to the trays below. Chevrons are provided with an overspray wash system to prevent clogging in the 8-cm (3-in.) spacings. The overspray consists of blended pond water applied at a rate of 14.5 l/sec (230 gpm).

The saturated flue gas exits the mist eliminator at a temperature of 50°C (122°F) and enters an in-line stack gas steam tube reheat system, which provides a temperature boost of 28°C (50°F) before the gas is discharged to the atmosphere. The reheater in each module consists of eight banks of steam tube bundles of four rows per bank†. The steam tubes are 1.6-cm (5/8-in.) outer diameter, 316L stainless steel bare tubes which convey 0.96 kg/sec (7600 lb/hr) of 965 kPa (140 psig), 365°C (690°F) extraction steam. Each reheat unit also contains a set of four soot blowers, which operate every 4 hours to clean the reheater tubes.

After passing through the reheat section, the gases enter a common plenum at a temperature of 78°C (172°F). The gas then feeds into six ducts 3.6 m (12 ft) in diameter and is discharged to a 312-m (700-ft) steel-lined stack via six 5200-kW (7000-hp) induced-draft booster fans. One booster fan is installed in each of the six ducts that discharge into the base of the stack at equal 60 degree spacings.

The venturi scrubber and countercurrent tray absorber of each module use a common recirculation tank for completion of chemical reactions, addition of fresh alkali, and discharging of spent slurry and fly ash to the waste disposal area. The venturi recirculation line from the tank to the scrubber is equipped with

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* Currently three of the eight modules include two-stage chevron mist eliminators. The remaining five modules include single-stage mist eliminators.

† Currently three of the eight modules include eight banks of four tubes/bank steam heat exchangers. The remaining five modules include four banks of four tubes/bank steam heat exchangers.

a hydroclone which centrifugally separates large particles of scale from the scrubbing liquor and discharges them through a screen back to the recirculation tank. This minimizes plugging of the nozzles and strainers and reduces erosion in the pumps, pipes, and nozzles.

Scrubbing wastes in the amount of 3200 Mg (3500 ton) of solids per day are removed from the module recirculation tanks through a spent slurry valve and rubber-lined pipes to a 0.65-km^2 (160-acre) settling pond. Clear makeup water is pumped from the pond, and the water loop is closed by recycling ball mill and module makeup water into the system. Water is recycled to the process at a rate of 447 kg/sec (3,550,000 lb/hr). The settling pond is equipped with an overflow weir, which permits water to flow into a larger pond that is used primarily for plant cooling water. Utility analyses of the return water concentrations of the calcium and sulfate ion species to be 856 and 2130 ppm, respectively.

PROCESS CHEMISTRY: PRINCIPAL REACTIONS

The chemistry involved in the wet limestone system at the La Cygne Power Station is complex, and details are beyond the scope of this report. The principal chemical mechanisms are discussed briefly in the following paragraphs.

The first and most important step in the wet-phase absorption of SO_2 from the flue gas stream is diffusion of the species from the gas to the liquid phase. Sulfur dioxide is an acidic anhydride that readily forms an acidic species in the presence of water,

$$SO_2 \uparrow \rightleftharpoons SO_{2(aq.)}$$

$$SO_{2(aq.)} + H_2O \rightleftharpoons H_2SO_3$$

In addition, some SO_3 is formed by the additional oxidation of the SO_2 in the flue gas stream.

$$2SO_2 \uparrow + O_2 \uparrow \rightleftharpoons 2SO_3 \uparrow$$

This species, like SO_2, is an acidic anhydride, readily forming

an acid in the presence of water,

$$SO_3 \uparrow \rightleftharpoons SO_{3(aq.)}$$

$$SO_{3(aq.)} + H_2O \rightleftharpoons H_2SO_4$$

The sulfurous and sulfuric acid compounds are polyprotic species, the sulfurous species weak, and the sulfuric species strong. Their respective dissociation reactions into ionic species occur in the following manner:

$$H_2SO_3 \rightleftharpoons H^+ + HSO_3^-$$

$$HSO_3^- \rightleftharpoons H^+ + SO_3^=$$

$$H_2SO_4 \rightleftharpoons H^+ + HSO_4^-$$

$$HSO_4^- \rightleftharpoons H^+ + SO_4^=$$

Analogous to the oxidation of sulfur dioxide to form sulfur trioxide, sulfite ion has a limited tendency to undergo oxidation by dissolved oxygen in the slurry,

$$2SO_3^= + O_{2(aq.)} \rightleftharpoons 2SO_4^=$$

The limestone is originally slurried with water for use in the scrubbing system. The absorbent, which is approximately 85 percent calcium carbonate by weight, is quite insoluble in water, the solubility increasing only slightly as the temperature increases. The slurry dissolves and ionizes into an acidic aqueous medium when introduced into the scrubbing system, yielding the ionic products of calcium, carbonate, bicarbonate, and hydrogen.

$$CaCO_3 \downarrow \rightleftharpoons CaCO_{3(aq.)}$$

$$CaCO_{3(aq.)} \rightleftharpoons Ca^{++} + CO_3^=$$

$$Ca^{++} + H^+ + CO_3^= \rightleftharpoons CaHCO_3^+$$

$$CaHCO_3^+ \rightleftharpoons Ca^{++} + HCO_3^-$$

The chemical absorption of sulfur dioxide occurs in the wet scrubber vessels and is completed in the external recirculation tank. The reaction products precipitate as calcium salts, and the scrubbing solution is recycled to the scrubbers for further use. The principal reaction mechanisms for product formation and precipitation are as follows.

$$Ca^{++} + SO_3^{=} \rightleftharpoons CaSO_3$$

$$CaSO_3 + 1/2\ H_2O \rightleftharpoons CaSO_3 \cdot 1/2\ H_2O$$

$$Ca^{++} + SO_4^{=} \rightleftharpoons CaSO_4$$

$$CaSO_4 + 2H_2O \rightleftharpoons CaSO_4 \cdot 2H_2O$$

The hydrated calcium sulfite and calcium sulfate products, along with the collected fly ash and unreacted limestone, are then transferred to the sludge pond for settling and final disposal. The supernatant is recycled to the system.

Reactions in the recirculation tank are completed in the 5.5 to 6.0 pH range. Table 4 lists the various components present and their corresponding concentrations, as determined by the utility.

Table 4. COMPOSITION AND CONCENTRATION OF THE RECIRCULATION TANK SPECIES

Calcium carbonate	70 g/l (0.6 lb/gal.)
Calcium sulfite	35 g/l (0.3 lb/gal.)
Calcium sulfate	25 g/l (0.2 lb/gal.)
Fly ash	40 g/l (0.3 lb/gal.)
Solids	10 percent, weight
pH	5.5 to 6.0

PROCESS OPERATING PARAMETERS

The utility and the system supplier have made many major modifications to the scrubbing system, resulting in alteration of many of the original design parameters. The modifications were intended primarily to reduce or ameliorate problems encountered in operation of the boiler and FGD facility. Section 4 explains the rationale and nature of these modifications. Actual operating conditions are described below:

(1) Each of the original seven scrubber-absorber modules was designed to treat approximately one-seventh of the

total boiler flue gas at full-load capacity [185 m^3/sec at 140°C (394,285 acfm at 285°F)]. Because of scrubber process control considerations, however, the unit was forced to operate at a maximum continuous generating capacity well below full load (i.e., 700 to 720 MW instead of 820 MW). The actual flue gas flow per module at maximum continuous generating capacity (actual operating conditions) was approximately 130 to 140 m^3/sec (280,000 to 300,000 acfm) at 57°C (135°F). The addition of an eighth scrubber-absorber module in June 1977 allowed operation of the unit at full load capacity.

(2) Each module is equipped with a 100-percent-capacity venturi recirculation pump rated at 472 l/sec (7750 gpm), and supplied with 261-kW (350-hp) drives. After hydroclones were installed in the venturi recirculation lines, however, the pressure head of the recirculation pump increased, and the recirculation rate is now approximately 305 l/sec (5000 gpm).

(3) The design liquid-to-gas ratio (L/G) for the venturi scrubber is 2.4 l/m^3 (18 gal./100 acf) of gas. The actual L/G is approximately 1.6 l/m^3 (12 gal./1000 acf).

(4) The original design reheater exit temperature was 63.9°C (147°F). Because this temperature was insufficient to protect downstream equipment from corrosion and provide adequate plume buoyancy, additional reheat was supplied by providing 287°C (550°F) steam to the reheat coils and by injecting 257°C (495°F) hot air from the boiler air heaters into the gas stream prior to the reheat section. This latter practice was reduced when the eight scrubber-absorber module was placed in service in April 1977 (almost all the hot air from the boiler air heaters was required for full-load operations). Additional reheat banks were installed to maintain an exit temperature of 88°C (190°F).

(5) The original design stoichiometric requirement for limestone addition was 1.7. The actual amount was maintained at twice stoichiometric during manually controlled operations. Limestone addition was tied into the automatic pH-controlled circuit in early 1977. The success of this mode of operation has reduced the limestone stoichiometric requirement to the original design value of 1.7, reducing daily consumption from 5000 Mg (5500 ton) to 1360 Mg (1500 ton).

PROCESS CONTROL

The process control system relies primarily on the pH and the solids content of the scrubbing solution. The pH is maintained between 5.6 and 5.8, a range that permits optimum performance of the stainless steel components. Chemical reactions within the scrubbing system also depend on pH. If the pH exceeds 5.8, limestone utilization decreases, stoichiometric requirements increase, and soft scale tends to accumulate rapidly. If the pH drops below 5.6, a hard gypsum scale builds up within a short time. Operation below this pH range tends to promote acid and chloride attack, especially in creviced and uncleared scrubber areas. The 5.6 to 5.8 pH range is maintained by regulating the amount of limestone added to the system. The pH of the scrubbing solution is monitored by a meter located in the wall wash header at the throat area inside the venturi scrubber. The amount of limestone feed is regulated as a function of the pH readings inside the venturi. Specifically, if the solution pH drops below 5.6, more limestone is added automatically by opening the slurry feed valves. The utility also stores an adequate supply of lime in the scrubber area to cover emergencies caused by a sudden pH drop.

The solids content of the scrubbing solution is maintained in the range of 18 to 20 percent. Recirculation of the scrubbing liquor at this level allows maximum SO_2 removal with minimum problems. The abrasion of scrubbing equipment, such as pumps and

piping, and the corrosion of scrubber internals, such as mist eliminators and reheaters, are reduced and kept to a minimum. The solids content of the scrubbing solution is monitored in the venturi recirculation line by a nuclear density meter. When the solids content exceeds the 20 percent level, a bleed stream is discharged from the recirculation line to the 0.65-km^2 (160-acre) settling pond.

Figure 4 presents a diagram of the major equipment and control components of a typical La Cygne FGD module. Tables 5, 6, and 7 summarize operating and design parameters and specifications for the major components.

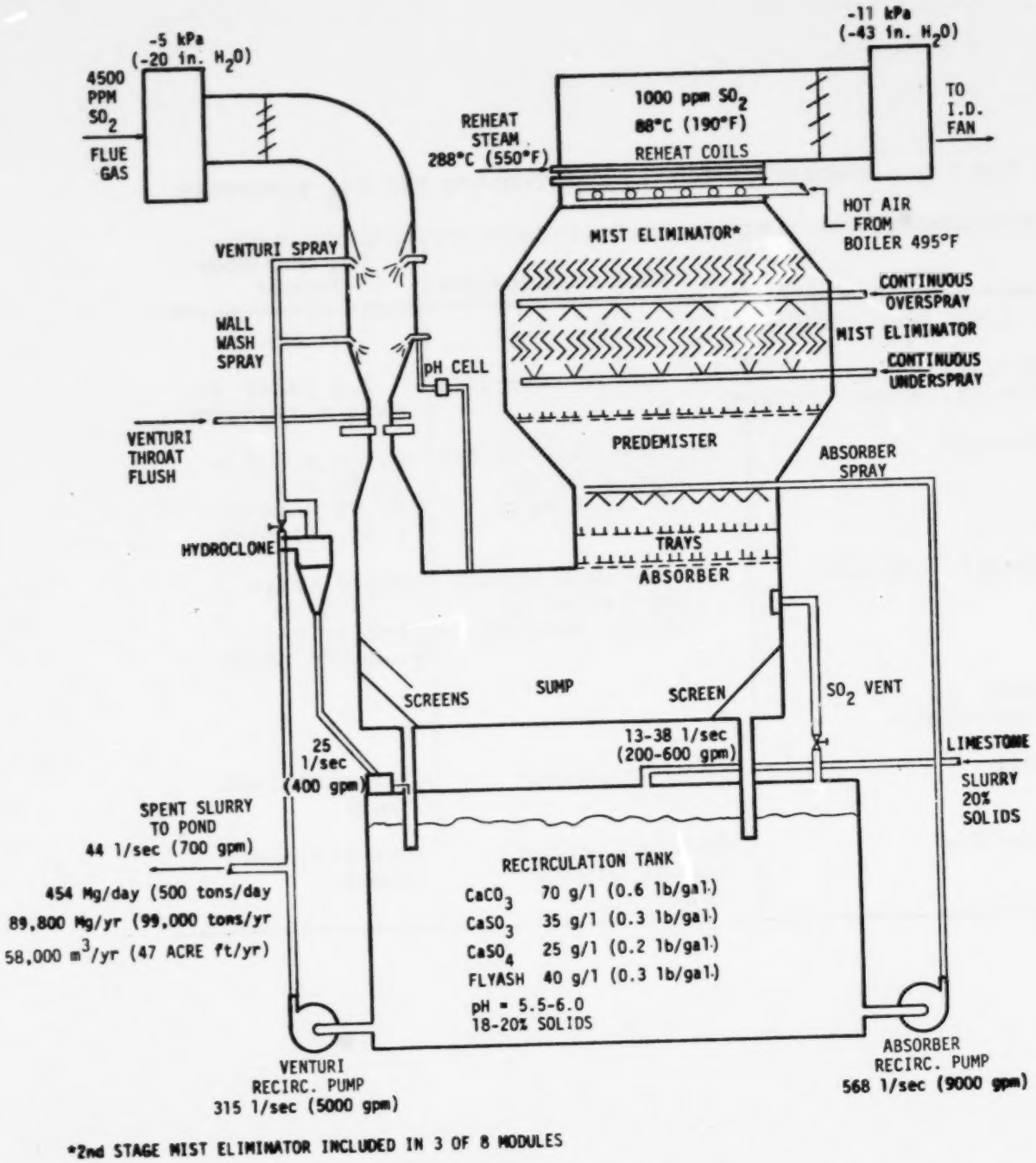

Figure 4. Gas and liquid circuits of a La Cygne FGD module.

Table 5. SUMMARY OF DATA: PARTICULATE AND SO_2 SCRUBBERS

	Venturi scrubber	SO_2 scrubber tower
L/G, l/m^3 (gal./1000 acf)	1.6 (12)	3.5 (26.5)
Superficial gas velocity, m/sec (ft/sec)	40-45 (130-150)	2.6 (8.4) at mist eliminator
Dimensions	6.55 m (21-1/2 ft) long x 56 cm (22 in.) wide	9.7 m x 4.9 m x 20 m (32 ft x 16 ft x 65 ft) high
Equipment internals	Adjustable throat maintained at widest opening	Sieve trays 3.5-cm (1-3/8-in.) diameter holes
Material of construction:		
Shell	316L stainless steel	316L stainless steel
Internals	Kaocrete ceramic, (throat blocks area)	316L stainless steel

Table 6. SUMMARY OF DATA: FGD SYSTEM HOLD TANKS

	Recirculation tank	Limestone slurry makeup tank
Total number of tanks	8	2
Dimensions, m (ft)	9 (30) dia. x 7.3 (24) high	11 (36) dia. x 7.9 (26) high
Retention time at full load, minutes	8	120
Temperature, °C (°F)	49 (121)	Ambient
pH	5.5-6.0	7.5
Limestone concentration, %	8-10	20
Total solids concentration, %	18-20	
Material of construction	Rubber-lined carbon steel	Rubber-lined carbon steel

Table 7. TYPICAL PRESSURE DROP ACROSS COMPONENTS OF FGD TRAIN

Equipment	Pressure drop, kPa (in. W.G.)
Venturi scrubber	1.7 (7)
SO_2 absorber trays	1.5 (6)
Predemister	0.3 (1.2)
Mist eliminators	0.1 (0.2)
Reheater	0.9 (3.6)
Ductwork	1.0 (4)
Total FGD system	5.5 (22)

SECTION 4

FGD SYSTEM PERFORMANCE

RATIONALE OF FACILITY OPERATION

The FGD system at the La Cygne power station is an integral part of the power production system. Because the modules provide primary control of both SO_2 and particulates, the ductwork design does not permit flue gas to bypass the FGD system. Each module can be removed and isolated from the gas stream for maintenance, but not without reducing boiler loads.

The La Cygne boiler-scrubber design is such that emphasis has had to be placed on optimizing FGD system operation. This emphasis, which is not necessary for many emission control systems that incorporate dry particulate removal components upstream of wet scrubbers (thus allowing flue gas bypass of the FGD system), has had the following ramifications.

1. Before installation of the eighth module, the maximum continuous load capacity of La Cygne Unit 1 was 700 MW. This power generation capacity allowed maximum scrubbing system availability over an extended period of time. Exceeding this output made the scrubbers susceptible to chemical and mechanical problems, which resulted in forced outages and subsequent cutbacks in power production.
2. The utility appointed a separate superintendent and support crew for FGD operation and maintenance. This crew consists of operators, maintenance, and administrative personnel totalling 54 people, who are deployed over all three operating shifts.
3. An extensive preventive maintenance program is followed. Generally, the night-load requirement is such that the

unit operates at 50 to 67 percent capacity during an 8- to 10-hour period extending from late evening to early morning. During this period, one or two of the modules are shut down for inspection, cleanout, and if necessary, modifications and repairs. Shutdowns are rotated so that preventive maintenance is conducted on each module at least once each week.

4. The purpose of the FGD system is to enable the utility to achieve compliance with air quality regulations while producing the maximum number of kilowatt hours of electricity. Thus, achieving optimum daily operations takes precedence over research and development of scrubbing technology. Priority for solution of problems is in this order: mechanical, chemical, and instrumental. At present, the utility is emphasizing reliability of mechanical components. Investigations into the chemical and instrumental aspects of the system will proceed when the utility believes that mechanical reliability has been achieved.
5. Two scrubber modules (A and D) are being used for limited research testing. Tests are concentrating primarily on modifications of the mechanical design of the modules.

OPERATING HISTORY AND PERFORMANCE

Trial operation of the boiler and FGD system began on December 26, 1972. Numerous problems, mostly mechanical, were encountered. These problems (primarily concerned with fabrication and design) were corrected, and the boiler and FGD system began operating commercially in June 1973.

Many major mechanical problems accompanied this subsequent operation as well, along with some chemical problems. These include massive formation of scale, serious corrosion, fan blade vibration, problems with limestone handling and slurry preparation, plugging of nozzles, control malfunctions, and failure of

valves, piping, pump liners, and expansion joints.

An extensive preventive maintenance program and continuing system modifications have resulted in a steady annual increase in the number of FGD scrubber operation hours since start-up in June 1973. Total system availability index values for 1974, 1975, 1976, and 1977 averaged 76, 84, 92, and 93 percent, respectively. Table 8 summarizes the performance of the La Cygne FGD system on an individual module basis.

The La Cygne air quality control system is designed for 98.75 percent particulate removal which corresponds to an outlet particulate emission of 60 ng/J (0.13 lb/10^6 Btu) heat input. The system is designed for 80 percent SO_2 removal, which corresponds to an outlet SO_2 emission rate of 860 ng/J (2 lb/10^6 Btu) heat input. Design values are based on high-sulfur Kansas coal with a heating value of 19 to 23.8 MJ/kg (8200 to 10,200 Btu/lb), an ash content 20 to 30 percent, and a sulfur content of 5 to 6 percent.

The utility conducted two system performance tests to determine actual particulate and SO_2 removal efficiency values. Tests were conducted under two different boiler load conditions: a full-load capacity of 800 to 830 MW and a maximum continuous capacity of 700 to 720 MW. A 4-hour, full-load test was conducted on March 24, 1975. The unit maintained a load range of 800 to 830 MW throughout the test, with seven modules fully loaded. The SO_2 removal efficiency of the total system, for the six modules from which the results were obtained, was 76.2 percent. An 8.5-hour test was conducted by an independent test group on May 15, 1975, to ascertain maximum continuous capacity. The load range during the test was 700 to 720 MW. The particulate and SO_2 removal efficiencies for seven modules combined were 98.2 and 80.14 percent, respectively. Tables 9 and 10 present details of these performance tests.

Table 8. MODULE AVAILABILITY SUMMARY - LA CYGNE JANUARY 1974 TO DECEMBER 1977

Period	Boiler operating hours	Module availability, percent							
		A	B	C	D	E	F	G	Average
January 74	364	49	32	44	87	23	37	81	50
February 74	364	66	68	59	76	52	100	65	69
March 74		Turbine and boiler shutdown							
April 74	332	67	70	75	88	74	100	88	80
May 74	500	69	83	78	85	78	84	80	80
June 74	480	92	84	83	90	82	83	87	86
July 74	313	75	80	80	81	85	79	77	80
August 74	571	90	90	73	81	81	78	99	85
September 74	606	69	88	73	76	83	89	86	81
October 74	662	71	61	59	81	79	93	89	76
November 74	386	90	71	60	61	84	85	84	76
December 74		Turbine and boiler shutdown							
Total	4578	75	74	69	81	74	84	83	76

(Continued)

Table 8. (Continued).

Period	Boiler operating hours	Module availability, percent							
		A	B	C	D	E	F	G	Average
January 75		Turbine and boiler shutdown							
February 75		Turbine and boiler shutdown							
March 75	394	82	96	90	76	93	82	96	90
April 75		Turbine and boiler shutdown							
May 75	683	95	85	94	90	90	89	83	89
June 75	667	88	85	84	85	84	86	89	86
July 75	590	78	90	90	84	85	87	85	86
August 75	630	75	88	87	78	92	85	83	84
September 75	610	78	84	84	85	79	78	74	80
October 75	231	66	77	46	74	72	73	65	68
November 75	346	93	90	80	93	96	89	94	91
December 75	597	91	87	81	85	87	89	84	86
Total	5048	83	87	82	83	86	85	84	84

(Continued)

Table 8. (Continued).

Period	Boiler operating hours	Module availability, percent							
		A	B	C	D	E	F	G	Average
January 76	618	86	85	91	72	84	52	84	83
February 76	594	94	90	86	91	92	93	95	92
March 76	643	92	90	88	93	94	91	91	91
April[a] 76	143	92	91	89	97	96	98	95	94
May 76	436	96	92	93	96	89	95	96	94
June 76	656	93	94	94	95	92	94	91	93
July 76	688	96	95	92	93	93	94	94	94
August[b] 76	521	94	93	92	94	92	90	88	92
September 76		Turbine repair, stack relining							
October[b] 76	256	97	97	98	89	96	96	96	96
November 76	627	95	93	94	95	94	93	94	94
December 76	706	87	89	81	94	94	95	91	90
Total	5888	93	91	90	91	92	88	92	92

[a] A scheduled turbine and boiler outage lasting 24 days occurred during the month.

[b] The unit was taken out of service on August 24 for turbine blade repairs. KCP&L took advantage of this turbine outage to reline the stack. The outage lasted from August 24 to October 20.

(Continued)

Table 8. (Continued).

Period	Boiler operating hours	Module availability, percent								
		A	B	C	D	E	F	G	H	Average
January 77	539	94	90	95	95	95	92	90		93
February 77	590	93	93	93	94	93	94	88		93
March 77	558	94	92	86	94	91	94	90		92
April 77	384	96	94	97	94	95	96	95		95
May 77	15			Turbine repair, stack relining						
June 77				Turbine repair, stack relining						
July 77	485	95	93	94	95	95	95	95	95	95
August 77	501	89	55	93	93	90	93	93	94	87
September 77	524	93	94	89	90	93	95	92	93	92
October 77	456	91	96	89	94	93	94	88	93	92
November 77	234	93	96	93	94	92	92	96	95	94
December 77				Turbine repair						
Total	4286	93	89	92	94	93	94	92	94	93

Table 9. LA CYGNE UNIT 1 4-HOUR FULL-LOAD TEST

Date: March 24, 1975
Time: 6:10 p.m. to 10:25 p.m.
Power: 800 to 830 MW
Ambient Temp: 60°F.

Parameter	Modular values						
	A	B	C	D	E	F	G
Gas flow, m^3/sec (cfm)	178 (380,000)	169 (360,000)	188 (400,000)	192+ (410,000+)	188 (400,000)	183 (390,000)	160 (340,000)
Throat, cm (in.)	56 (22)	52 (22)	56 (22)	56 (22)	56 (22)	56 (22)	56 (22)
Reheat temp, °C (°F)	77 (170)	82 (180)	82 (180)	66 (150)	66 (150)	77 (170)	85 (185)
Absorber pump	ON	ON	ON	ON	ON	ON	ON
Venturi pump flow l/sec (gpm)	252 (4000)	252 (4000)	315 (5000)	252 (4000)	315 (5000)	315 (5000)	315 (5000)
Venturi ΔP, kPa (in. H_2O)	1.9 (8.0)	1.9 (7.5)	-	2.7 (11.0)	26 (10.0)	2.7 (11.0)	2.2 (9.0)
Reheater ΔP, kPa (in. H_2O)	1.0 (4.0)	0.87 (3.5)	0.75 (3.0)	0.87 (3.5)	0.25 (1.0)	1.1 (4.5)	3.1 (12.5)
Absorber mist eliminator ΔP, kPa (in. H_2O)	-	1.4 (5.5)	-	2.1 (8.5)	2.1 (8.5)	2.2 (9.0)	2.2 (9.0)
Hot air damper pos., % open	46	23	44	-	48	32	64
Reheat outlet damper pos., % open	51	37	98	84	100	96	100
Scrubber outlet press., kPa (in. H_2O)	9.5 (38.3)		9.6 (38.4)				
I.D. fan, amp	540	520	620	600	380	380	
I.D. fan inlet damper pos., % open	100	98	98	100	100	23	
Solution pH	5.95	5.89	5.80	5.68	5.92	5.79	5.73

(Continued)

Table 9. (Continued).

Sulfite concentration lb/gal. (g/l)	0.34 (41.1)	0.30 (36.2)	0.38 (45.9)	0.30 (35.4)	0.38 (45.1)	0.25 (29.4)	0.46 (54.7)
Carbonate concentration lb/gal. (g/l)	0.78 (94.4)	0.70 (84.1)	0.58 (69.4)	0.70 (84.4)	0.77 (91.9)	0.91 (109.0)	0.64 (76.6)
SO_2 removal efficiency, %	75.1	79.1	72.2	72.0		82.9	75.7
Inlet, ppm	5700	5138	5516	4995	5700	5017	5120
Outlet, ppm	1419	1075	1533	1220		857	1243

Table 10. LA CYGNE UNIT 1 8-HOUR MAXIMUM CONTINUOUS LOAD TEST

Date:	May 15, 1975
Time:	11:30 a.m. to 8:00 p.m.
Power:	700 to 720 MW Continuous
Ambient Temp:	72°F
Overall average SO_2 removal:	80%
Overall particulate removal:	98.2%

Parameter	A	B	C	D	E	F	G
Gas flow, m^3/sec (cfm)	150 (320,000)	132 (280,000)	141 (300,000)	160 (340,000)	150 (320,000)	141 (300,000)	141 (300,000)
Throat, cm (in.)	56 (22)	52 (22)	56 (22)	56 (22)	56 (22)	56 (22)	56 (22)
Reheat temp, °C (°F)	77 (170)	88 (190)	77 (170)	64 (148)	82 (180)	71 (160)	88 (190)
Absorber pump	ON	ON	ON	ON	ON	ON	ON
Venturi pump flow l/sec (gpm)	249 (4000)	244 (4000)	244 (4000)	244 (4000)	244 (4000)	244 (4000)	244 (4000)
Venturi ΔP, kPa (in. H_2O)	1.7 (7)	1.5 (6)	1.7 (7)	1.7 (7)	2.0 (8)	1.7 (7)	2.0 (8)
Reheater ΔP, kPa (in. H_2O)	1.0 (4)	0.7 (3)	0.7 (3)	2.0 (8)	1.5 (6)	2.7 (11)	2.0 (8)
Absorber mist eliminator ΔP, kPa (in. H_2O)		1.0 (4)		2.0 (8)	2.0 (8)	2.0 (8)	2.0 (8)
Hot air damper pos., % open	46	20	50		50	94	100
Reheat outlet damper pos., % open	40	35	55	75	82	100	100
Scrubber outlet press., kPa (in. H_2O)	9.5 (38)			7.0 (28)			
I.D. fan, amp	460	480	460	400	400	440	
I.D. fan inlet damper pos., % open	60	60	60	60	60	32	
Solution pH	5.95	6.02	5.93	5.80	5.98	5.90	5.90

(Continued)

Table 10. (Continued).

Sulfite concentration lb/gal. (g/l)	0.45 (53.9)	0.31 (37.0)	0.31 (37.4)	0.49 (58.4)	0.51 (61.6)	0.46 (54.7)	0.54 (64.8)
Carbonate concentration lb/gal. (g/l)	0.88 (105.0)	0.71 (85.3)	0.90 (108)	0.63 (75.3)	0.91 (109)	0.78 (93.1)	0.80 (95.9)
SO_2 removal efficiency, %	76	81	81	82	77	83	81
Inlet ppm	4506	4297	4663	4273	4982	4156	4834
Outlet ppm	1068	834	892	776	1121	704	917

START-UP AND SUBSEQUENT OPERATION: PROBLEMS AND SOLUTIONS

The start-up and ensuing operation of the FGD system at La Cygne were accompanied by major problems. Solutions to these problems were conceived and implemented primarily by utility personnel as a result of continuing modification work and an extensive preventive maintenance program. The major problem areas and their respective solutions are discussed in the following paragraphs.

Scale Formation

The buildup of a hard gypsum scale film inside the modules has been a persistent problem since start-up. The primary areas on which this scale forms are absorber internals, sieve trays, the predemister sieve tray, mist eliminators, reheat tubes, and induced-draft fan blades.

To control scale, the utility instigated a program that emphasizes regular cleaning and washing as well as fine control of scrubbing solution chemistry and the use of specified construction materials in areas prone to develop scale.

Each scrubber is cleaned and washed weekly (i.e., one module is taken out of service nightly on a rotational basis). A three-man crew works inside the scrubber module for 10 to 12 hours (from approximately 9 p.m. to 7 a.m.). They use large amounts of fresh water to flush away scale accumulations and a 31-MPa (4500-psi) needle stream of water to clean the more difficult spots. As a last resort, the hard gypsum scale is chipped off manually, sometimes with sledge hammers.

The use of 316L stainless steel as the material of construction for the La Cygne scrubbers has also helped to prevent scale buildup, especially in highly susceptible areas, since scale has less tendency to adhere to the surfaces of equipment constructed of 2.75 percent molybdenum bearing chromium-nickel stainless steel.

Corrosion

Corrosion has been a serious problem in reheaters, expansion joints, induced-draft fans, breeching, and the carbon steel liner of the stack. Serious corrosion problems have been combatted by methods similar to those used to combat scale formation. Thoroughly cleaning each module weekly virtually eliminates corrosion throughout the system by minimizing the formation of crevices in which acids and chlorides can concentrate and attack metal surfaces. Corrosive attack in crevices can become especially severe when dirty scrubbers circulate solution with a low pH and a high chloride content.

The chloride content in the slurry at the point of discharge of the bleed is 300 to 500 ppm. Pond water returned to the process contains an average of 168 ppm of chlorides. These concentration levels in conjunction with the 5.6- to 5.8- pH range maintained in the scrubber provide an optimum performance environment for the stainless steel components.

The use of compatible stainless steel components has been an important factor in preventing severe corrosion. Type 316L stainless steel was originally specified throughout the scrubber system from a point just before the venturi throat through the duct beyond the reheaters. The only exceptions were the fiber-glass-reinforced polyester (FRP) chevron mist eliminators and the Type 304 stainless steel reheater tubes. Extensive pitting corrosion, some chloride stress corrosion cracking, and subsequent mechanical failure around the tube supports occurred in the original steam tubes. To rectify this problem all the reheat tube bundles that failed were replaced with sturdier ones constructed of Type 316L stainless steel. The sturdier design has reduced the likelihood of mechanical failure at the supports and provided a stronger support platform for the cleaning crew. Also, when a module is taken out of service for cleaning and repairs, steam flow continues through the tubes, thereby keeping the surface temperature above the acid dew point until thorough flushing has been completed.

Scale carryover to the induced-draft fans can provide areas and crevices that foster corrosive attack. To resist the effects of acid corrosion, various epoxy paints are applied to the fans every 8 to 10 months. The utility is also initiating a program to protect those areas and mating surfaces most affected by acid runs by cladding them with Inconel 625 stainless steel. Serious corrosion is also a problem in the breeching from the fans to the stack and in the carbon steel liner of the stack. These latter areas have also been coated with an epoxy paint (Plasite 4005) that resists corrosion and erosion.

Plugging

Plugging in the La Cygne modules occurs as deposition of soft solids on the internals. These soft solids originate from three different sources: fly ash, calcium carbonate, and calcium sulfite. Calcium sulfite forms what is commonly known as soft scale. Soft scale tends to accumulate rapidly when the pH of the scrubbing solution exceeds the control level (5.6 to 5.8) and enters the alkaline range. This results in the precipitation of large leaf-like masses of calcium sulfite on the internals. Because this material is soft and easily altered mechanically, it provides deposition areas for the calcium carbonate and fly ash material in the scrubbing solution. High calcium carbonate concentrations in the scrubbing solution result from the high stoichiometric feed rate of limestone slurry.

Areas that have been susceptible to plugging are sieve trays, walls, predemister sieve trays, mist eliminators, reheater tubes, and induced-draft fan blades. Freshwater sprays are used to remove accumulations of soft deposits from module internals.

Erosion

The venturi throat and the sump floor immediately below the venturi are areas within the modules that are susceptible to wear and abrasion. To protect these areas, silicon-carbide brick and cementitious coating are applied to the stainless steel.

Erosion has also been detected on the stainless steel slurry nozzles and the carbon steel coated induced-draft fans.

Another preventive measure involves rubber-lining the process piping network to protect the carbon steel base from abrasive slurry. This has been generally successful, although there have been a few reported incidents of wear in the area of the spent slurry valves. This wear was attributed to the throttling action of the valve to modulate the flow of slurry. The problem was solved by operating the valve only in a completely open or completely closed position.

Mechanical Failures

Several miscellaneous mechanical problems have occurred during FGD operations. The major problems are described briefly in the following paragraphs.

The rubber lining in venturi pumps on the circulation tanks has been damaged many times, primarily because of frequent plugging of the strainer at the suction end of the pump. As plugging causes the flow to cease or to be drastically reduced, the pump cavitates and the liner is sucked into the path of the impeller and shredded. The suction strainers were located inside the recirculation tank, and the tank had to be drained to clean them. Installation of a hydroclone in the recirculation line of each module for the purpose of extending the life of the limestone slurry spray nozzles on the venturi scrubber and reducing wear and erosion in the slurry recirculation loop solved pump problems as well. The hydroclone separates the larger particles of scale from the main slurry steam by means of centrifugal action. This made the strainer unnecessary, and its removal eliminated plugging problems.

The mist eliminators and gas reheater tubes have been susceptible to heavy scaling and plugging. Droplets of slurry are carried over with the flue gas and deposited on the mist eliminators, which are made of Z-shaped fiberglass boards. As the slurry builds up, the gas flow is restricted and its velocity

through the mist eliminator increases, causing solids carryover and deposition on the reheater tubes. Some slurry carryover also reaches the induced-draft fan and is deposited on the fan blades.

These interrelated problems of carryover to the mist eliminator, the reheater, and the induced-draft fan have necessitated many modifications to equipment and corrections in operating procedures. A continuous overspray now keeps the mist eliminators clean. The steam soot blower has been modified so that it is reasonably successful in maintaining the reheaters, thereby greatly reducing the need for fan washing.

Another modification involved replacing 304 stainless steel reheater tubes with 316L stainless steel tubes. The rapid corrosion of the former material prompted the utility to install hot air headers and inject a slip stream of hot combustion gas into the saturated flue gas upstream of the reheater. This additional reheat load was required to raise the temperature above the acid dew point at which the 304 stainless steel bundles were susceptible to attack [88° to 93°C (190 to 200°F)]. Formerly, 17 to 20 percent of the reheat was provided in this manner. This procedure has been reduced because of the sturdier 316L stainless steel bundles and also because most of the entire hot combustion air stream is required for full-load capacity operation.

Problems have occurred with the induced-draft fans since these units were first balanced in September 1972. Initially the fans were sensitive to imbalance, and severe vibration in the fan housing resulted from the fans operating close to the critical speed. The vibration caused cracks in the inlet cones, and additional stiffeners had to be installed to strengthen the housing.

Another problem involved high running temperatures of the thrust collars on the fan bearings, which reached the 180°F alarm set point within a short time after the fans were started. Examination of the bearings revealed that the thrust collars were not stable and their movement attributed to air turbulence

in the inlet ductwork, causing the rotor to shift from side to side. Several aerodynamic configurations were tried to eliminate this air turbulence. A splitter foil and directional vanes were installed in the duct and in the fan inlet box, but the thrust collars continued to overheat and to move during operation. The temperature was finally controlled by cutting oil grooves in the thrust collar and installing forced-lubrication systems on all the fans. These modifications effected a decrease in the thrust collar temperature to a range of 140° to 160°F. Movement of the thrust collars were checked by installing split backup collars designed to give an interference fit.

Problems with the induced-draft fan began with the initial firing of the boiler. Fly ash and slurry carried over from the scrubber and deposited on the blades of the impeller aggravated the tendency of the fan to be out of balance and promoted fan blade erosion. (One blade was nearly destroyed by erosion.) Examination of all the blades by magnaflux revealed several cracks, indicating the need for reinforcement. By June 1974 all I.D. fan rotors had been replaced with units of heavier design. Shaft diameter was increased from 51 to 61 cm (20 to 24 in.). Radial tip blades and side plates of the wheels are 1.6 cm (5/8 in.) thick instead of 0.64 cm (1/4 in.). The thick center plate was scalloped to hold down the weight, and the critical frequency was moved farther away from the operating speed to reduce the tendency to vibrate. The leading edge of each blade was covered with a stainless steel clip to deter erosion. Although fly ash carry-over still requires intermittent washing of the fans, the cleaning frequency is being steadily reduced.

Fly ash carry-over has also caused erosion of the inlet and outlet dampers of the induced draft fans. Metal on the dampers has been rewelded or replaced several times. Deposits have interferred with operation to the extent that dampers have bound and pins have sheared. Seal air has been provided to keep the bearings clean.

Limestone and coal are stored separately in two adjacent

piles. A single conveying system was used to transport both materials to the boiler on a time-sharing basis. Most of the problems created by this arrangement were logistic. However, the size of the fines had to be increased to 5 x 0.3 cm (2 x 1/8 in.) because fines of proper size, 2 x 0 cm (3/4 x 0 in.), clogged the delivery chutes. This created other problems in that the steel balls in the mills were not large enough to properly grind the larger fines. This resulted in a limestone slurry of undesirable consistency. The addition of a separate limestone delivery system has since alleviated these problems.

The quality of the limestone shipped to the plant was also a source of some concern. The presence of large amounts of gangue and other foreign matter resulted in occasional plugging of the limestone feed nozzles. To correct this, the utility installed catch buckets to filter out larger inert materials from the limestone before it enters the preparation tanks.

The limestone for the FGD system comes from a local quarry. Two different grades come from the same quarry, a top cut and a lower cut. The top cut, which is off-white to brownish, has a high content of iron oxides and grinds easily. The lower cut, which is gray to white, is more difficult to grind. Because of the different physical and chemical properties, each requires different process control ranges to maintain optimum utilization and minimize scaling and corrosion.

Since initial start-up of the system, spray nozzle arrangement in the scrubber modules has been a source of many problems, including plugging and poor spray distribution. The utility is now attempting to recitify these problems by installing ceramic spinner-vane spray nozzles.

SYSTEM ECONOMICS

The total cost of the La Cygne emission control system to date amounts to approximately 22 percent of the total plant cost of $213.5 million. This translates into an installed value of $46.8 million or $59/kW. The utility invested an additional $7

million to achieve optimum system performance, $5.2 million of which covers the installation of the eighth scrubber module. In 1977 energy costs for Unit 1 averaged 8.23 mills/kWh. Approximately 21 percent of this total was devoted to the emission control system, including the purchase and preparation of the limestone and the operation and maintenance of the system hardware.

Unit 2, a 630-MW coal-fired power generator, was placed in commercial service in May 1977. This unit burns low-sulfur (0.48 percent) Wyoming coal supplied by Amax Coal Company mines in the Gillette area. Compliance with new source performance standards for SO_2 does not require FGD, but an ESP is used to control particulate emissions. The strategy for Unit 2 was developed along different lines from that for Unit 1 because of coal supply commitments. The coal supplied for the boiler in Unit 1 originates from nearby surface mines operated by the Pittsburgh & Midway Coal Mining Company. Total deposits are estimated to be 64 Tg (70 million tons), which is sufficient to supply the fuel needs of the unit over its designed 30-year life span. Because local coal could not be obtained for Unit 2, the utility negotiated a long-term commitment for rail delivery of low-sulfur Wyoming coal, which the boiler will burn at a rate of 1.8 million Mg (2 million tons) per year.

Tables 11 and 12 present operating and capital costs for the La Cygne Unit 1 scrubbing system. FGD operating and maintenance costs cover approximately 4 years of operation following commercial start-up. Capital cost figures include unit allocations and coal and limestone costs.

Table 11. FGD OPERATING COSTS, LA CYGNE UNIT 1, JUNE 1973 TO SEPTEMBER 1977

Description	1973 operation[a]		1974 operation[b]		1975 operation[c]		1976 operation[d]		1977 operation[e]	
	dollars	mills/kWh	dollars	mills/kWh	dollars	mills/kWh	dollars	mills/kWh	dollars	mills/kWh
Operating labor	162,934	0.233	284,541	0.223	601,029	0.265	683,939	0.229	524,409	0.292
Operating materials	3,480	0.005	67,032	0.053	195,926	0.086	415,226	0.139	189,945	0.106
Maintenance labor	189,400	0.259	401,414	0.315	416,206	0.184	358,941	0.129	363,159	0.202
Maintenance materials	441,737	0.604	335,486	0.263	386,397	0.171	93,292	0.574	947,000	0.528
Limestone	264,514	0.362	780,297	0.613	1,256,048	0.554	1,717,949	0.574	1,013,717	0.565
Total	1,062,065	1.453	1,868,770	1.467	2,885,606	1.260	3,269,347	1.102	3,038,230	1.693

[a] 1973 operation figures include operation from full commercial start-up on June 1 to December 31.

[b] 1974 operation figures are based upon a 23 percent unit capacity factor.

[c] 1975 operation figures are based upon a 32 percent unit capacity factor.

[d] 1976 operation figures are based upon a 44 percent unit capacity factor.

[e] 1977 operation figures include only the first 9 months of operation. Unit capacity factor for this period was 44 percent.

Table 12. TOTAL CAPITAL COSTS FOR THE LA CYGNE UNIT 1 POWER GENERATING UNIT AND FGD FACILITY

Description	Capital costs (1977 dollars)	
	Total	$/kW
Power generation facility	166,586,000	208
Scrubbing facility	46,861,000	59
Total plant costs	213,447,000	267
Capital cost basis:		
Coal: $11,919/Mg ($10.813/ton) $0.56/GJ ($0.535/10^6 Btu) 2.2 GG/year 2.4 x 10^6 tons/year) usage		
Limestone: $3.381/Mg ($3.068/ton) 454 Mg/year (500,000 tons/year) usage		
Unit rating: 820 MW, net		

APPENDIX A

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Kansas City Power and Light (KCP&L)
2. Main office: Kansas City, Missouri
3. Plant name: La Cygne Station
4. Plant location: La Cygne, Kansas (Linn County)
5. Responsible officer: Mr. Trask
6. Plant manager: Charles Ryan
7. Plant contact: Cliff McDaniel
8. Position: Superintendent of scrubbing operations
9. Telephone number: 913/757-4451
10. Date information gathered: June 23, 1976

Participants in meeting	Affiliation
Cliff McDaniel	KCP&L
Ray Cain	KCP&L
G.A. Isaacs	PEDCo Environmental, Inc.
B.A. Laseke	PEDCo Environmental, Inc.
T.C. Ponder	PEDCo Environmental, Inc.
R. Klier	PEDCo Environmental, Inc.

B. Plant and Site Data

1. UTM coordinates: _____

2. Sea Level elevation: _____

3. Plant site plot plant (Yes, No): No
(include drawing or aerial overviews)

4. FGD system plan (yes, No): No

5. General description of plant environs: Flat, rural, no major industry in the area

6. Coal shipment mode: Coal is delivered to the plant in off-the-road 108-Mg (120-ton) trucks from nearby surface mines operated by the Pittsburgh & Midway Coal Mining Company.

C. FGD Vendor/Designer Background

1. Process name: Wet limestone

2. Developer/licensor name: Babcock & Wilcox

3. Address: Power Generation Group, 20 S. Van Buren Ave., Barberton, Ohio

4. Company offering process:

Company name: Babcock & Wilcox

Address: 20 S. Van Buren Avenue

Location: Barberton, Ohio

Company contact: Jack Stewart

Position: Sales Manager

Telephone number: (216) 753-4511

5. Architectural/engineers name: _____

Address: _____

Location: _____

Company contact: _____

Position: _____

Telephone number: _____

D. Boiler Data

1. Boiler: La Cygne Unit 1

2. Boiler manufacturer: Babcock & Wilcox

3. Boiler service (base, standby, floating, peak):

Base load: Maximum continuous generating capacity for two-thirds of a service day; two-thirds capacity during the remainder of the service day.

4. Year boiler placed in service: 1973

5. Total hours operation: 19,000 hr (approximate to Nov. 1977)

6. Remaining life of unit: _____

7. Boiler type: Dry bottom, pulverized-coal, cyclone-fired, supercritical, once-through balanced-draft

8. Served by stack no.: One

9. Stack height: 200 m (700 ft)

10. Stack top inner diameter: _____

11. Unit ratings (MW):

Gross unit rating: 874 MW

Net unit rating without FGD: 844 MW

Net unit rating with FGD: 820 MW

Name plate rating: 874 MW

12. Unit heat rate: 11,400 kJ/kWh)10,800 Btu/kWh)

Heat rate without FGD: N/A

Heat rate with FGD: 11,400 kJ/kWh (10,800 Btu/kWh)

13. Boiler capacity factor, (1976): 57%

14. Fuel type (coal or oil): Coal

15. Flue gas flow:

Maximum: 1,297 m^3/sec (2,760,000 acfm)

Temperature: 140°C (285°F)

16. Total excess air: 18-20%

17. Boiler efficiency:

E. Coal Data

1. Coal supplier:

Name: Pittsburgh & Midway Coal Mining Co.

Location: Linn County, La Cygne, Kansas

Mine location: La Cygne - 3.2 km (2 miles) from plant

County, State: Linn County, Kansas

Seam:

2. Gross heating value: 21-23 MJ/kg (9000-9700 Btu/lb)

3. Ash (dry basis): 24-25%

4. Sulfur (dry basis): 5-6%

5. Total moisture: 9-10%

6. Chloride: 0.02-0.03%

7. Ash composition (See Table A2)

8. Coal Analysis: (See Comments, Section M)

NA -Not Applicable

Table A2. ASH COMPOSITION

Constituent	Percent weight
Silica, SiO_2	46.05
Alumina, Al_2O_3	14.07
Titania, TiO_2	1.02
Ferric oxide, Fe_2O_3	19.23
Calcium oxide, CaO	6.86
Magnesium oxide, MgO	1.02
Sodium oxide, Na_2O	0.60
Potassium oxide, K_2O	2.48
Phosphorous pentoxide, P_2O_5	0.15
Sulfur trioxide, SO_3	7.85
Other	0.67
Undetermined	

F. Atmospheric Emission Regulations [Data given in ng/J (lb/10^6 Btu)]

1. Applicable particulate emission regulation

   a) Current requirement: 56 (0.128)

      AQCR priority classification: III

      Regulation and section No.: Kansas Air Pollution Emission Control Regulation 28-19-31A

   b) Future requirement (Date:): _____

      Regulation and section No.: _____

2. Applicable SO_2 emission regulation

   a) Current requirement: 640 (1.5)*

      AQCR Priority Classification: III

      Regulation and section No.: Kansas Air Pollution Emission Control Regulation 28-19-31C

   b) Future requirement (Date:) _____

* Sulfur emission regulation limitation. Boiler installed prior to Federal NSPS - subject to Kansas Dept. of Health regulation.

Regulation and section No.: _____

G. Chemical Additives: (Includes all reagent additives - absorbents, precipitants, flocculants, coagulants, pH adjusters, fixatives, catalysts, etc.)

1. Trade name: Limestone

   Principal ingredient: $CaCO_3$ (85-93%)

   Function: Scrubbing reagent

   Source/manufacturer: Bates City Rock Co.

   Quantity employed: 454 Mg/yr (500,000 tons/yr)

   Point of addition: Milling system

2. Trade name: Lime

   Principal ingredient: CaO

   Function: Emergency pH control additive

   Source/manufacturer: _____

   Quantity employed: Emergency only - has never been required

   Point of addition: Recirculation tanks

3. Trade name: N/A

   Principal ingredient: _____

   Function: _____

   Source/manufacturer: _____

   Quantity employed: _____

   Point of addition: _____

4. Trade name: N/A

   Principal ingredient: _____

   Function: _____

   Source/manufacturer: _____

   Quantity employed: _____

Point of addition: _____

5. Trade name: N/A

Principal ingredient: _____

Function: _____

Source/manufacturer: _____

Quantity employed: _____

Point of addition: _____

H. Equipment Specifications

1. Electrostatic precipitator(s) N/A

Number: None

Manufacturer: _____

Particulate removal efficiency: _____

Outlet temperature: _____

Pressure drop: _____

2. Mechanical collector(s) N/A

Number: None

Type: _____

Size: _____

Manufacturer: _____

Particulate removal efficiency: _____

Pressure drop: _____

3. Particulate scrubber(s)

Number: Eight, one per scrubbing train

Type: Variable-throat venturi

Manufacturer: Babcock & Wilcox

Dimensions: 6.6 m x 56 cm (21.5 ft x 22 in.)

Material, shell: 316L SS

Material, shell lining: Kaocrete ceramic

Material, internals: None

No. of modules: One per scrubbing train, eight total

No. of stages: One

Nozzle type: Coors ceramic spinner vane

Nozzle size:

No. of nozzles: 48 spray and 32 wall wash

Boiler load: 100% for all 8

Scrubber gas flow: 160 m^3/sec @ 141°C (345,000 acfm @ 285°F) (design value)

Liquid recirculation rate: 238 l/sec (5000 gpm)

Modulation: None

L/G ratio: 1.6 l/m^3 (12 gal./1000 acf)

Scrubber pressure drop: 1.7 kPa (7 in H_2O)

Modulation: None (see Comments, Section M)

Superficial gas velocity: 39.6 m/sec (130 ft/sec)

Particulate removal efficiency: 98.2%

Inlet loading: 4250 ng/J (9.9 lb/10^6 Btu)

Outlet loading: See SO_2 absorber, item No. 4

SO_2 removal efficiency: Unknown

Inlet concentration: 4500

Outlet concentration: See SO_2 absorber, item No. 4

4. SO_2 absorber(s)

Number: Eight, one per scrubbing train

Type: Two-stage sieve tray absorber

Manufacturer: Babcock & Wilcox

Dimensions: 9.7 x 4.9 x 19.8 m (32 x 16 x 65 ft)

Material, shell: 316L SS

Material, shell lining: None

Material, internals: 316L SS sieve trays

No. of modules: One per scrubbing train, eight total

No. of stages: 2

Packing type: N/A

Packing thickness/stage: N/A

Nozzle type: Coors ceramic spinner vane

Nozzle size: 1.9 cm (0.75 in.)

No. of nozzles: 16

Boiler load: 100% for all 8 absorbers

Absorber gas flow: 112 m^3/sec @ 50°C (238,500 acfm @ 122°F) (design value)

Liquid recirculation rate: 500 l/sec (9000 gpm)

Modulation:

L/G ratio: 3.5 m^3/sec (26.5 gal/1000 acf)

Absorber pressure drop: 1.5 kPa (6 in. H_2O)

Modulation: None

Superficial gas velocity: 4.6 m/sec (15 ft/sec)

Particulate removal efficiency: See particulate scrubber, Item No. 3

Inlet loading: See particulate scrubber, Item No. 3

Outlet loading: 77 ng/J (0.13 lb/10^6 Btu)

SO_2 removal efficiency: 80%

Inlet concentration: See particulate scrubber, Item No. 3

Outlet concentration: 1000 ppm

5. Predemister

Number: Eight, one per scrubbing train

Type: Sieve tray, 3.5-cm (1.375-in.) diameter holes

Materials of construction: 316L SS

Pressure drop: 0.3 kPa (1.2 in. H_2O)

Source of water:

6. Mist eliminator(s) (Eight, one per scrubbing train)

Number:

Type: Chevron

Materials of construction: FRP (Durakane)

Manufacturer: B&W

Configuration (horizontal/vertical): Horizontal

Distance between scrubber bed and mist eliminator:

3.6 m (12 ft)

Mist eliminator depth: 26.2 cm (10.3 in.) per stage

Vane spacing: 7.6 cm (3 in.)

Vane angles: 45°

Type and location of wash system: Continuous blended pond water overspray [14.5 l/sec (230 gpm)]

Superficial gas velocity: 2.6 m/sec (8.4 ft/sec)

Pressure drop: 50 Pa (012 in. H_2O)

Comments: Three of the eight modules currently have two-stage, three-pass mist eliminators, the remaining five have one-stage, three-pass units.

7. Reheater(s): 1 per scrubbing train, 8 total

Type (check appropriate category):

☒ in-line

☒ indirect hot air

☐ direct combustion

☐ bypass

☐ exit gas recirculation

☐ waste heat recovery

☐ other

Gas conditions for reheat: (per module)

Flow rate: 145 m^3/sec (307,500 acfm)

Temperature: 122°F

SO_2 concentration: 1000 ppm

Heating medium: Extraction steam

Combustion fuel: N/A

Percent of gas bypassed for reheat: N/A

Temperature boost (ΔT): 28°C (50°F)

Energy required: 0.65% of boiler input

Comments: The reheaters are stainless steel bare tubes which convey 0.96 kg/sec (7600 lb/hr) of 965 kPa (140 psig) 365°C (690°F) extraction steam.

8. Fan(s) (9 fans total)

Type: 3 forced-draft (FD) fans, 6 induced-draft (ID) booster fans

Materials of construction:

Manufacturer: Green Fuel Economizer Co. and Sturtevant Co.

Location: 3 FD fans with boiler; 6 ID fans downstream of reheaters

Fan/motor speed:

Motor/brake power: 5250 W (7000 hp)

Variable speed drive: _____

9. Tank(s)

Function	Number	Dimensions	Capacity	Retention time	Materials of construction
Limestone slurry stage	2	11 m ϕ x 8 m (36 ft ϕ x 26 ft)	450,000 l (200,000 gal.)	120 min	Rubber-lined carbon steel
Slurry recirculation	8	9 m ϕ x 7 m (30 ft ϕ x 24 ft)	440,000 l (116,000 gal.)	8 min	Rubber-lined carbon steel

10. Recirculation/slurry pump(s)

Function	Number	Manufacturer	Type	Capacity	Motor
Venturi recirculation	8	A-S-H	Rubber lined	315 l/sec (5000 gpm)	260 kW (350 hp)
Absorber recirculation	8 8	A-S-H A-S-H	Rubber lined	(9000 gpm)	300 kW (400 hp)

11. Thickener(s)/clarifier(s) N/A

Number: _____

Type: _____

Manufacturer: _____

Materials of construction: _____

Configuration: _____

Diameter: _____

Depth: _____

Rake speed: _____

12. Vacuum filter(s) N/A

Number: _____

Type: _____

Manufacturer: _____

Materials of construction: _____

Belt cloth material: _____

Design capacity: _____

Filter area: _____

13. Centrifuge(s) N/A

Number: _____

Type: _____

Manufacturer: _____

Materials of construction: _____

Size/dimensions: _____

Capacity: _____

14. Interim sludge pond(s)

Number: One

Description: Settling pond equipped with overflow weirs

Area: 0.65 km^2 (160 acres)

Depth: 3.0-3.5 m (10-12 ft)

Liner type: None

Location: Plant grounds

Typical operating schedule: Clarified solution overflows into larger settling pond

Ground water/surface water monitors: _____

15. Final disposal site(s)

Number: _____

Description: _____

Area: _____

Depth: _____

Location: _____

Transportation mode: Pipe

Typical operating schedule: Continuous

16. Raw materials production

Type: Limestone ball mills

Number: Two

Manufacturer: Koppers

Capacity: 28 kg/sec (110 tons/hr)

Product characteristics: Limestone rock ground to a firmness of 95% minus 200 mesh at 66% solids before slurried

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s)

Design life: Life span of unit

Elapsed operation time: 20,000 hr (approximate)

Cleanout method: Manual: 3-man maintenance view

Cleanout frequency: One module nightly/once per week

Cleanout duration: 8-10 hr

Other preventive maintenance procedures: _____

2. Absorber(s)

Design life: Life span of unit

Elapsed operation time: 20,000 hr (approximate)

Cleanout method: Manual: three-man maintenance crew

Cleanout frequency: One module nightly/once per week

Cleanout duration: 8-10

Other preventive maintenance procedures: _____

_____

3. Reheater(s)

Design life: 1-2 years

Elapsed operation time: _____

Cleanout method: Soot blowers

Cleanout frequency: _____

Cleanout duration: _____

Other preventive maintenance procedures: Cleaned during manual preventive maintenance, one module once per week

4. Scrubber fan(s) (Same as scrubbers and absorbers)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: _____

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

5. Mist eliminator(s) (Same as scrubbers and absorbers)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: _____

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

6. Pump(s) (Same as scrubbers and absorbers)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: _____

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

7. Vacuum filter(s)/centrifuge(s) N/A

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: _____

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

8. Sludge disposal pond(s)

Design life: _____

Elapsed operation time: _____

Capacity consumed: _____

Remaining capacity: _____

Cleanout procedures: _____

_____

J. Cost Data

1. Total installed capital cost: $46.8 MM ($59/kW)
2. Annualized operating cost: $3.038 MM (1.693 mills/kWh)
3. Cost analysis (see breakdown: Table A2) See comments (below)
4. Unit costs
   a. Electricity: _____
   b. Water: _____
   c. Steam: _____
   d. Fuel (reheating/FGD process): _____
   e. Fixation cost: _____
   f. Raw material: _____
   g. Labor: _____

   _____

   _____
5. Comments: Details on the total installed capital and operating costs for La Cygne No. 1 are provided in the text of the report (see Section 4, System Economics, and Tables 13 and 14)

Table A2. COST BREAKDOWN

Cost elements	Included in cost estimate		Estimated amount or % of total capital cost
	Yes	No	
A. Capital Costs			
Scrubber modules	☐	☐	_____
Reagent separation facilities	☐	☐	_____
Waste treatment and disposal pond	☐	☐	_____
By-product handling and storage	☐	☐	_____
Site improvements	☐	☐	_____
Land, roads, tracks, substation	☐	☐	_____
Engineering costs	☐	☐	_____
Contractors fee	☐	☐	_____
Interest on capital during construction	☐	☐	_____
B. Annualized Operating Cost			
Fixed Costs			
Interest on capital	☐	☐	_____
Depreciation	☐	☐	_____
Insurance and taxes	☐	☐	_____
Labor cost including overhead	☐	☐	_____
Variable costs			
Raw material	☐	☐	_____
Utilities	☐	☐	_____
Maintenance	☐	☐	_____

K. Instrumentation

A brief description of the control mechanism or method of measurement for each of the following process parameters:

- Reagent addition: _____

  _____

- Liquor solids content: _____

  _____

- Liquor dissolved solids content: _____

  _____

- Liquor ion concentrations

  Chloride: _____

  _____

  Calcium: _____

  _____

  Magnesium: _____

  _____

  Sodium: _____

  _____

  Sulfite: _____

  _____

  Sulfate: _____

  _____

  Carbonate: _____

  _____

  Other (specify): _____

  _____

- Liquor alkalinity: _____

- Liquor pH: _____

- Liquor flow: _____

- Pollutant (SO_2, particulate, NO_x) concentration in flue gas: _____

- Gas flow: _____

- Waste water _____

- Waste solids: _____

Provide a diagram or drawing of the scrubber/absorber train that illustrates the function and location of the components of the scrubber/absorber control system.

Remarks: A thorough discussion of the instrumentation and and process control network for the La Cygne scrubbing system is provided in Section 3 (see Process Control)

L. Discussion of Major Problem Areas: see text - Start-up and and Subsequent Operation: Problems and Solutions

1. Corrosion: Some

2. **Erosion:** Some

3. **Scaling:** See text - Start-up and Subsequent Operation: Problems and Solutions

4. **Plugging:** See text - Start-up and Subsequent Operation: Problems and Solutions

5. **Design problems:** See text - Start-up and Subsequent Operation: Problems and Solutions

6. **Waste water/solids disposal:** See text - Start-up and Subsequent Operation: Problems and Solutions

7. Mechanical problems:

M. General comments:

1. La Cygne coal proximate and ultimate analysis:

Proximate		Ultimate	
Volatile	28.63	Moisture	8.60
Fixed carbon	37.94	Carbon	51.93
Ash	24.36	Hydrogen	3.43
Moisture	9.07	Nitrogen	0.94
	100.00	Chlorine	0.02
		Sulfur	5.39
		Ash	24.36
		Oxygen	5.33
			100.00
Heat content, MJ/kg (Btu/lb)	22 (9421)		
Grindability	59.59		

2. The venturi scrubbers are maintained at widest opening with no modulation; the eighth module includes a fixed throat venturi.